〔 Appendix Documents 〕

[Appendix Document 1] Fossil Identification of Benthos

Samples used for the identification of fossils are listed in Table 1-1. The species were determined by relevant method for ach specimens described in the following.

1. Analysis Method

・Foraminifer

Samples were washed through 63μm sieve, and dried under room temperature. Dried samples were scattered on the tray with sieve, and were used for the identification of species under microscopic observation and for counting numbers of population. On the planktonic foraminifer, only specimens larger than 150μm were treated for faunal assemblage analysis purpose. Fragmental materials such as other fossil remains and mineral grains were inspected as well. Samples contain pumice and other volcanic fragments as well as radiolarian, planktonic and benthic foraminifer fossils, on the other hand, fragments of manganese crust were not inspected. By this method, identifiable foraminifer species were found from 2 samples of the 03503 sampling station (sample No.03S2027SC01: FS01, depth; 0 t0 5cm and FS03, depth; 20 to 25cm).

・Radiolarian

For the separation of population of radiolarian fossils with siliceous skeleton and Ichtyoliths with calcium phosphate skeleton, samples were washed by warm water and residuals on the sieves of two different opening, 175μm and 63μm were collected for the analysis. Residuals were put into slide glasses using ultraviolet fortifier and are microscopically inspected. By this method, all of the identifiable radiolarian fossils were inspected from the residual samples. Preliminary observation gave information that there contained about 80 tropical species in a slide sample and was judged radiolarian chronology of tropical sea area could be applied, so that the age determination was done following mainly by the paper by Sanpino and Nigrini (1998).

・Ichtyolith

Ichtyolith fossils were preliminarily found many populations in residual samples passed through the sieve opening of larger than 175μm, all the population on the samples were picked up under the microscope, and they were put in the slide glass using ultraviolet fortifier and were inspected under biological microscope. Identifiable ichtyolith fossils were found from all the samples by this method. In the inspection done in the previous year, fossil age determination was made referring the report by Doyle and Riedel (1979), but more recent, about 20 papers were found by reference paper survey on ichtyolith fossils, fossil age determination was done on the basis of the paper by Doyle and Riedel (1985) in this report.

2. Occurrence

① Foraminifer

All the analyzed samples occur planktonic foraminifer fossils, but many of them are fragmented and receiving strong dissolution. However, there still occur fossils with calcareous skeleton, it is hard to consider that the environment is largely beyond carbonate compensation depth –CCD (the depth calcareous fossils are dissolved). On the other hand, from the extent of fragmentation and alteration of faunal assemblages, it is considered that the environment reaches lisocline (the depth of calcareous fossil assemblages alteration) (Table 2-1).

Photographs of main planktonic fossils are shown in the last of this report.

② Radiolarian and Ichtyolith

The result of age determination by radiolarian fossils and the list of related radiolarian species used for examination is summarized in Table 1-3 and the occurrence list of ichtyolith is shown in Table 1-4. Photographs of main radiolarian fossils and ichtyolith fossils are given in the last of this report.

a) Point No 03503 Sample No. 03S2027SC01 FS01 – 04

FS01 (Depth; 0 to 5 cm): Mainly brownish clayey material but contain sand size grains of volcanogenic minerals and abundant well-preserved radiolarian fossils occur. Ichtyolith fossils are common and it rarely contains benthonic foraminifer fossils. Radiolarian fossils are well preserved as a whole.

FS02 (Depth; 10cm to 15cm): Mainly brownish clayey material. Containing grains smaller the size than 175μm are mainly volcanogenic minerals and radiolarian fossils. Grain materials larger the size than 175μm are foraminifer fossils, succeeded by radiolarian fossils, but volcanogenic minerals are small in content. Ichtyoliths are not so many but commonly observed.

Radiolarian fossils are well preserved as a whole.

FS03 (Depth; 20cm to 25cm): Mainly brownish clayey material. Grains less than 175μm are mainly volcanogenic minerals and radiolarian fossils. Grains larger than 175μm are foraminifers succeeded by volcanogenic minerals and radiolarian fossils. Ichtyoliths are small in number but commonly observed. Foraminifer fossils are more fragmented than those of the FS02 sample.

Radiolarian fossils are well preserved as a whole.

FS04 (Depth; 30cm to 35cm): A little darker brownish color clayey materials than FS01 to FS03 samples. Compared with FS01 to FS03 samples, grains smaller than 175μm are composed mostly of volcanogenic minerals and radiolarian fossils are little smaller in number. Ichtyolith fossils are small in number, but commonly observed. Very rarely, it contains foraminifer fragments but they are completely fragmented.

Radiolarian fossils are well preserved as a whole.

b) Point No 03513 Sample No. 03S2327SC01 FS01 – 04

FS01(Depth 0 to 1cm): Mainly brownish clayey material. Grains less than 175μm contain sub-rounded volcano-clastics and radiolarian fossils are common. Grain materials of the size larger than 175μm show dark brown color in naked eyes, and it is due to the color of benthtonic sandy foraminifers that form the shells selectively collecting dark brown minerals. Volcanogenic minerals grain and radiolarian fossils are also many. It rarely contains ichtyolith fossils.

Radiolarian fossils are well preserved as a whole.

FS02 (Depth 015 to 20cm): Mainly brownish clayey material. Grains smaller than175μm are mainly volcanogenic minerals and contain small amount of radiolarian. Different from FS01, grains larger than 175μm show brown to brownish color composed almost all of volcanogenic minerals. Rarely occurs radiolarian fossils and very few number of ichtyolith fossils.

Radiolarian fossils are well preserved as a whole.

FS03 (Depth 26cm to 28cm): Mainly brownish clayey material. Grains smaller than175μm are volcanogenic minerals and radiolarian fossils are few. Grains of larger than 175μm are, also different from FS01 and SF02, mainly composed of swelled, poorly vesicular weathered pumice, and radiolarian fossils and ichtyoliths larger than pumice size is rare.

Radiolarian fossils are well preserved as a whole.

FS04 (Depth 30cm to 33cm): Mainly brown clayey material. Grains smaller than175μm are mainly volcanogenic minerals and radiolarian fossils are not so many but commonly included. Grains of larger than 175μm are, like FS03, poorly swelled, vesicular weathered pumice. The number of radiolarian fossils larger than 175m are not so many but commonly included. Ichtyolith fossils were not observed.

Radiolarian fossils are well preserved as a whole.

c) Point No.03514 Sample No. 03S2326SC01 FS01 – 04

FS01 (Depth 0 to 3cm): Mainly brownish clayey material. The constituent of grains and grain size are different from the sample 03S0227SC01 or 03S2327SC01. Grains are more than 90% the size from 63μm -175μm, grains larger than 175μm are small.

FS01 (Depth 0 to 3cm): Mainly brownish clayey material and composed of terrigenous clastic materials. It contains commonly radiolarian fossils. Most of grains larger than 175μm seem weathered pumice. Grains show vesicular plume-like texture. It includes small numbers of radiolarian fossils and rarely includes fragments of sandy foraminifers. Shell forming grains show dark brownish color. Ichtyoliths are small in number but observed.

FS02 (Depth 10 to 15cm): Mainly brownish clayey material. Content of sandy grains are quite different from FS01. Grains of 63μm -175μm are composed of volcanogenic minerals and volcanic glasses are noteworthy. Radiolarian fossils are common. Grains larger than 175μm are composed of volcanogenic minerals mainly of poorly vesicular pumice and the surface are a little polished. Radiolarian fossils are rare and ichtyolith fossils are small in number but admitted.

FS03 (Depth 15 to 20cm): Mainly brown clayey material. Constituents of sandy grains are similar to FS02. . Grains of 63μm -175μm are composed of pale gray volcanogenic grains and the amount of volcanic glasses are by far common than FS02. Radiolarian fossils are common. Grains larger than 175μm are composed of volcanogenic minerals mainly of poor vesicular pumice and the surface are a little polished. Radiolarian and ichtyolith fossils are small in number but admitted.

FS03 (Depth 26 to 30cm): Mainly brownish clayey material. Constituents of sandy grains are similar to FS02 and FS03. Grains of 63μm -175μm are pale gray volcanogenic minerals and contain similar amount of volcanic glass with FS01. Radiolarian fossils are common. Grains larger than 175μm are composed of volcanogenic minerals mainly of poor vesicular pumice and pumice is increasingly weathered, showing some cases swelled or others shrunk texture.

Radiolarian fossils and ichtyolith fossils are small in number but admitted.

3. Geologic Time

① Foraminifera (population assemblage and geologic time)

In this survey, the determination of geologic time was made based upon geologic chronology proposed by Berggren *et al.* (1995). (Figure 1-1).

The datum plane shown in the figure is proposed to the assemblages of low latitude area and directly applicable to this survey area. In relation to the samples of this survey, applicable fossil datum plane is only the appearance *of Globorotaria truncatulinoides* (2.0Ma).

Assemblages: In the two core samples (FS01, FS02) from sampling point (03S2027SC01), assemblages of *Glbigerinoides conglobatus, Globorotalia ronda, Neogloboquadrina dutertrei, Sphaeroidinella dehiscens* are admitted. Small number of *Globorotalia viola, Globorotalia menardii, Globorotalia inflata*, are included but typical assemblage representing tropical region such as *Glbigerinoides rubber* or *Globigerinoides sacculifer* are rarely observed. From this, fossil assemblages of these samples seem to represent assemblages resistant to dissolution.

Geologic age

Fossil assemblages of weak to dissolution had been entirely lost in the core sample and thus the accurate discussion on the geologic age is difficult, however, the sample occurs *Globorotalia truncaturinoides* and the geologic time of deposition is assumed younger than Pleistocene (0.65Ma).

② Radiolarian and ichtyolith

a) Sampling point no. 03503 Sample no. 03S2027SC01 FS01-04

(Radiolarian)

All of the four samples FS01 to FS04 were determined to have deposited during the age 0.00-0.18 Ma (Ma=1million years ago) due to the fact that the samples occur *Buccinosphaera invaginata Haeckel* known to appear after 0.18Ma. This determination is conformable from the fact that the samples do not occur extinct species earlier than 0.18Ma. *Buccinosphaera invaginata* is not found from the FS02 sample, but the occurrence was confirmed from the upper and the lower sample and thus the FS02 sample was judged that it should include the species. Assumed deposition time of these samples from radiolarian fossil ranges from 0.0 – 0.18Ma.

This is conformable with the result of age determination of FS01 and FS03 sample by foraminifer fossil analysis.

・Consideration of reworked radiolarian

Reworked radiolarian derived fossils from sediments of upper Pliocene to middle Miocene origin are often reported from the equatorial Pacific Region. For this, careful examination was done on the samples, however, no such species were found.

(ichtyolith)

Three samples FS01, FS03, and FS04 were determined to have deposited 0.00-31.7Ma, and FS02 was determined to have deposited during 0.00 to 32.5 Ma. FS01, FS03, and FS04 sample contain *Flexed triangle 102-112 Doyle et al.* which is known to have appeared after 31.7Ma and thus the sediments are thought to have deposited after 31.7 Ma. This is conformable from the fact that none of three samples occur extinct species before 37.1Ma. FS02 sample occur *Triangle with high inline apex Doyle et al.* whose species appears after 32.5Ma and the sample is assumed to have deposited during 0.00 to 32.5Ma. This is conformable with the result that none of three samples occur extinct sub type species before 32.5Ma.

b) Locality no. 03513 Sample no. 03S2327SC01 FS01 – FS04

(Radiolarian)

All the sample of FS01 to FS04 of sample no. 03S2327SC01 was determined to have deposited during 0.18 to 0.42Ma. *Buccinosphaera invaginata Haeckel* which appears after 0.18Ma and *Collosphaera tuberosa Hackel* which appears after 0.54Ma is observed all of the four samples. On the other hand, *Axoprunum angelium (Campbell et Clark)*, extinct species of 0.42Ma is not found. This determination is conformable with the fact that the samples do not occur such extinct species as, *Amphirhopalum praeypsilon Sakai* extinct species of 0.54Ma, *Anthocyrtidium angulare Nigrini* extinct species of 1.11Ma, *Pterocanium prismatium Riedel* extinct species of 1.7Ma.

・Consideration of reworked radiolarian

The careful examination on reworked radiolarian derived fossils from sediments of upper Pliocene to middle Miocene origin that are often reported from the equatorial Pacific Region, was done on the samples, however, no such species were found.

(Ichtyolith)

The sample FS02 was determined to have deposited during 0.00-19.2Ma. The reason is that *Two triangle Doyle et al.* which appeared after 19.2Ma occurs in the sample. Other three samples, FS01, FS03, and FS04 were not able to determine the age.

c) Sample point no. 03514 Sample no. 03S2326SC01 FS01 – FS04

(Radiolarian)

The sample FS01, FS02, and FS03 were determined to have deposited during 0.18 – 0.42Ma. The species *Collosphaera tuberosa Hackel* appeared 0.54Ma and it occurs FS02 to FS04 sample suggesting deposition of all the samples is after 0.54Ma. *Stylocontarium acquilonium (Hays)*, extinct species around 0.42Ma occurs FS04 but does not occur in the FS01 to FS03 sample. Sediment between FS04 and FS03 are assumed 0.42Ma. On the other hand, *Buccinosphaera invaginata Haeckel*, appeared 0.18Ma is not found in any samples, the deposition time of FS01 to FS03 is interpreted between 0.18 to 0.42Ma.

・Consideration of reworked radiolarian

The careful examination on reworked radiolarian derived fossils from sediments of upper Pliocene to middle Miocene origin that are often reported from the equatorial Pacific Region, was done on the samples, however, no such species were found.

(ichtyolith)

FS01 is thought to have deposited between 0.0 –63.9Ma an FS03 and FS04 to be 0.0 – 32.5Ma. Deposition time of the FS02 could not be drawn out.

FS01 occurs *Triangle with triangular projection Helms and Riedel*, appeared after 63.9Ma and does not occur extinct sub type species after 63.9Ma and thus deposition time was estimated between 0.0 – 63.9Ma.

The sample FS03 and FS04 includes *Triangle with high inline apex Doyle et al.*, appeared after 32.5Ma and does not include extinct sub type species before 32.5 Ma, the deposition time is assumed between 0.0 – 32.5Ma. The FS02 sample does not occur fossil species capable of age determination and the assumption of deposition time by ichtyolith cannot be drawn out.

4. Rate of Deposition

Since vertical profiles of core samples are not continuous, it is hard to estimate accurate rate of deposition time from foraminifer fossils, however, taking into account of other data derived from radiolarian fossils an ichtyolith fossils, a rough assumption was calculated as below.

Sample point no.	Deposition time	Core Length	Rate of Deposition
03503(03S2027SC01)	0.00 ～0.18Ma	38cm	2.1mm/>1000years
03513(03S2327SC01)	0.18 ～0.42Ma	34cm	0.8mm～1.9mm/1000years
03514(03S2326SC01)	0.18 ～0.54Ma	30cm	0.6mm～1.9mm/1000years

5. Depositional Environment (Paleogeography)

① Foraminifer

The core sample (03S2027SC01 FS01 and FS03) occurs foraminifer assemblages known as common equatorial Pacific genus such as *Globorotalia tumida, G. menardii or Globorotalia ronda,* surely indicating tropical to subtropical geographic province and thus sediment of the core samples is assumed to have deposited at similar low altitude location as we see today.

The sample occurs both calcareous and arenaceous foraminiferal assemblages. Arenaceous assemblages include genera *Rhabdammina, Haplophragmoides, Recurvoides, Marsipella, Buzasina, Eggerella. Calcareous assemblages include genera*

Epistominella, Oridorsalis, Pullenia, Cibicides, Globocassidulina. Of them, *Olidorsalis umbonatus* is thought to indicate living condition of Lower to Middle Bathyal (800m to 2,500m) (Inoue, 1989; Akimoto and Hasegawa, 1989). The core sample was collected from much deeper (4,754m) depth and one possibility arises that these fossil assemblages have been transported to the present position. In any case, there include many populations of arenaceous genera and the deposition depth is assumed Lower Bathyal to Abyssal (probably more than 3,000m deep) depth, or almost same depth today.

② Radiolarian

a) Point no. 03503 Sample no. 03S2027SC01 FS01 – FS04

The living condition of radiolarian is assumed coexistence of tropical surface water and cool deep water or bottom water environment and negligible up welling current.

The existence of tropical surface waters is indicated by the occurrence of such tropical surface waters radiolarian assemblages as, *Spongaster tetras tetras (Haeckel), Didymocrytis tetrathalamus tetrathalamus (Haeckel), Lithopera bacca and Ehrenberg, Spongoplegma (?) arachdophorum (Haeckel).* According to the research work of surface sediments (Lombari and Boden, 1985), *S. tetras tetras (Haeckel)* is known to appear occupying more than 2% of population in the tropical surface sediments of the seawaters from latitude 5° to 7° N and the habitat extends tropical to subtropical seawaters from 30° N to 30° S latitude. It is also known from laboratory breeding test that the species can live under water temperature condition from about 20℃ to 30℃, and salinity from 30‰ to 40‰℃(Anderson, Bennet and Bryan, 1989). *D. tetrathalamus tetrathalamus* is observed widely distributed in the Pacific Ocean from 42° N to 45 ° S latitude (Lombari and Boden, 1985), it is associated with algae and lives in the sea of trans-light zone suitable for photosynthesis. According to the research of organic plankton collected depth-by-depth samples by sediment trap, *L. bacca* is known to live in seawaters shallower than 250m in the North Pacific Ocean (Gowing, 1993). *S. arachdophorum* is occurring often 10° N to 10° S tropical seawaters in the Indian Ocean(Nigrini, 1967) and certainly the tropical species.

Influence of cold water mass is assumed from the occurrence *of Actinomma (?) boreale (Cleve), Cycladophora davisiana Ehrenberg. A.(?) boreale* prefers cold water mass, and the habitat is known in the shallow offshore of Fjyord in Norway, and in case the Japan Sea, much warmer environment, the habitat is known in the cold sea water of deeper than 2,000m depth. The temperature is assumed lower than 10 ℃, and such cold water mass can be existed as deep water or bottom water. The water environment had been that of living condition of deepwater radiolaria and this is supported from the occurrence of *Cornutella profunda Ehrenberg* whose genus lives in water depth of 150m to 850m depth (Gowing, 1993). The cold water species can be proliferated under up welling water environment, however, in the survey area, *Tetrapyle octacantha Muller*, abundant species in up welling waters, is rarely observed in the sample, and the possibility to indicate the existence of up welling current is low.

Obtained assemblages consist of 80 species, and it does not show dominant deviation in faunal constituent. From this, it is assumed that the extent of bottom current is small and depositional environment was that falling marine snow had been accumulated as the source of autochtonous sediments. The size of radiolarian skeleton is almost all case larger than 63μm, or larger size than very fine sand grains. But the shell has many spines and the inside forms cavity, they are aerodynamically explained that shells are easily moved by subtle bottom current barely move silt size grain material, so that they are differentially sorted by difference of shapes, and deviated concentration of different assemblages easily occurs. By laboratory test, it is reported that shell movement takes place by water current with 1/10 of velocity to move very fine sand (Barrett, 1982).

As the remark of larger grain size of sediments than sand size grain, they are pelagic in origin without terrigenous clastic materials, and from large amount of radiolarian suggest the depositional environment was radiolarian productive oceanic environment. Viewing from calcareous microfossils, they are not observed in the FS01 sample but abundant fragmented fossil shells are observed in the FS02 and FS03 sample and completely fragmented in the FS04 sample. The core samples are unconsolidated sediments collected from sea bottom condition of free water circulation, and are thought under the condition of dissolution environment of calcium carbonate. As an explanation of the fact that calcareous fragments are abundantly remained in the lower FS02 and FS03 sample but not in the upper FS01 sample, the time of deposition of FS02 and FS03 had been very prolific time for foraminifers. However, fragments undertake dissolution and it becomes progressive from FS02 to FS03 and up to FS04 sample, which occurs very rarely the fragments. By this it makes difficult to assume the prolific foraminifer time range.

b) Point no. 03513 Sample no. 03S2327SC01 FS01 –FS04

The living condition of radiolarian is assumed coexistence of tropical surface water and cool deep water or bottom water environment and negligible up welling current.

The faunal assemblage of this sample is similar to the sample 03S2027SC01. The existence of tropical surface waters is indicated by the occurrence of such tropical surface waters radiolarian assemblages as, *Spongaster tetras tetras (Haeckel), Didymocrytis tetrathalamus tetrathalamus (Haeckel), Lithopera bacca and Ehrenberg, Spongoplegma (?) arachdophorum (Haeckel).* Influence of cold water mass is assumed from the occurrence of *Actinomma (?) boreale (Cleve), Cycladophora davisiana Ehrenberg.* Non-existence of up welling current is drawn from rare occurrence of *Tetrapyle octantha Muller,* abundant species in up welling waters, in the examined samples.

Obtained assemblages consist of 80 species, and it does not show dominant deviation in faunal constituent. From this, it is assumed that the extent of bottom current is small similar to Sample no. 03S2027 SC01and depositional environment was that falling marine snow had been accumulated as the source of autochtonous sediments. Inorganic grains are mainly volcanogenic grains suggesting pelagic environment. Compared with 03S2027SC01 sample, amount of radiolaria is small and production of radiolarian is smaller than that locality. On benthic environment, the depositional environment of the FS01 sample must have been suitable for sandy foraminifer, however, the detail of environment and the process of acquirement of dark color grains, are not clear. FS02 to FS04 sample lack sandy foraminifer so that benthic environment between FS01 and FS02 to FS04 seems different but the extent is not clear.

As the remarks of volcanogenic poorly vesicular pumice, FS01 is the best preserved, and as increases deposition depth, the extent of preservation becomes worse replacing alteration progresses, and FS04 is the most altered sample. This trend may suggest that alteration has been progressed following the order of deposition without transportation and this interpretation is conformable with negligible influence of bottom current suggested by radiolarian.

c) Point no. 03514 Sample no. 03S2326SC01 FS01 – FS04

The living condition of radiolarian is assumed coexistence of tropical surface water and cool deep water or bottom water environment and negligible up welling current.

The existence of tropical surface waters is indicated by the occurrence of such tropical surface water radiolarian assemblages as, *Spongaster tetras tetras (Haeckel), Didymocrytis tetrathalamus tetrathalamus (Haeckel), Lithopera bacca and Ehrenberg, Spongoplegma (?) arachdophorum (Haeckel).* Influence of cold water mass is assumed from the occurrence of *Actinomma (?) boreale (Cleve)* and *Cycladophora davisiana*

Ehrenberg. Non-existence of up welling current is drawn from rare occurrence of *Tetrapyle octantha Muller*, abundant species in up welling waters, in the examined samples.

Obtained assemblages consist of 80 species, and it does not show dominant deviation in faunal constituent. From this, the extent of influence of bottom current seems small similar to 03S2027SC01and 03S2327SC01, and depositional environment had been such that falling marine snow had been accumulated as the source of autochtonous sediments. The amount of radiolarian is much smaller and the prolific rate is thought lower than 03S2027SC01and 03S2327SC01.

Depositional environment is very differ between FS01 and FS02～FS04. FS01 is the depositional place of terrigenous clastics, on the contrary, FS02～FS04 are pelagic environment. FS01 is like FS01 of 03S2027SC01, occurs small numbers of sandy foraminifer fossils and suggesting both seabed condition was similar depositional environment. FS02～FS04are mainly volcanogenic minerals and volcanic glass is overwhelming compared to 03S2027SC01and 03S2327SC01. Compared with 03S2327SC01 with same radiolarian age determination, the extent of alteration of pumice is not so progressing and it shows a possibility that benthic condition was laid under chemical condition to limit dissolution.

Table 1-1　List of Samples for Microfossil Analysis

Station No.	Sample No.		Water depth(m)	Sample depth(m)	Sediment type	Foraminifer	Radiolarian	Nanno-plankton	Ichtyolith
03503	03S2027SC01	FS01	4,754	0.00 –0.05	silt	○	○		○
		FS02	4,754	0.10 –0.15	silt		○		○
		FS03	4,754	0.20 –0.25	silt	○	○		○
		FS04	4,754	0.30 –0.35	silt		○		○
03513	03S2327SC01	FS01	5,569	0.00 –0.01	v. fine sand		○		○
		FS02	5,569	0.15 –0.20	v. fine sand		○		○
		FS03	5,569	0.26 –0.28	v. fine sand		○		○
		FS04	5,569	0.30 –0.33	silt		○		○
03514	03S2326SC01	FS01	5,620	0.00 –0.03	v. fine sand		○		○
		FS02	5,620	0.10 –0.15	v. fine sand		○		○
		FS03	5,620	0.15 –0.20	v. fine sand		○		○
		FS04	5,620	0.26 –0.30	silt		○		○

Tble 1-2 Occurrence List of Foraminifera Fossils

A. Planktonic Foraminifera

Area	Sample No.		Depth(m)	Sampling Depth(m)	Abundance of Planktonic Foraminif	Preservation of Planktonic Foramir	Abundance of Benthic Foraminifera	Preservation of Benthic Foraminife	Geological Age	*Beella digitata*	*Globigerinoides conglobatus*	*Globorotalia inflata*	*Globorotalia menardii*	*Globorotalia ronda*	*Globorotalia truncatulinoides*	*Globorotalia tumida*	*Globorotalia viola*	*Neogloboquadrina dutertrei*	*Pulleniatina obliquiloculata*	*Sphaeroidinella dehiscens*		Total	Species Number
Niue	03S2027SC01	FS01	4,754	0-0.05	F	P	F	M	Pleistocene	1	16	1		22		8	2	1	1	4		55	8
		FS03		0.2-0.25	F	P	F	M	Pleistocene		47	2	2	22	1	14		8				96	7

B. Benthic Foraminifera

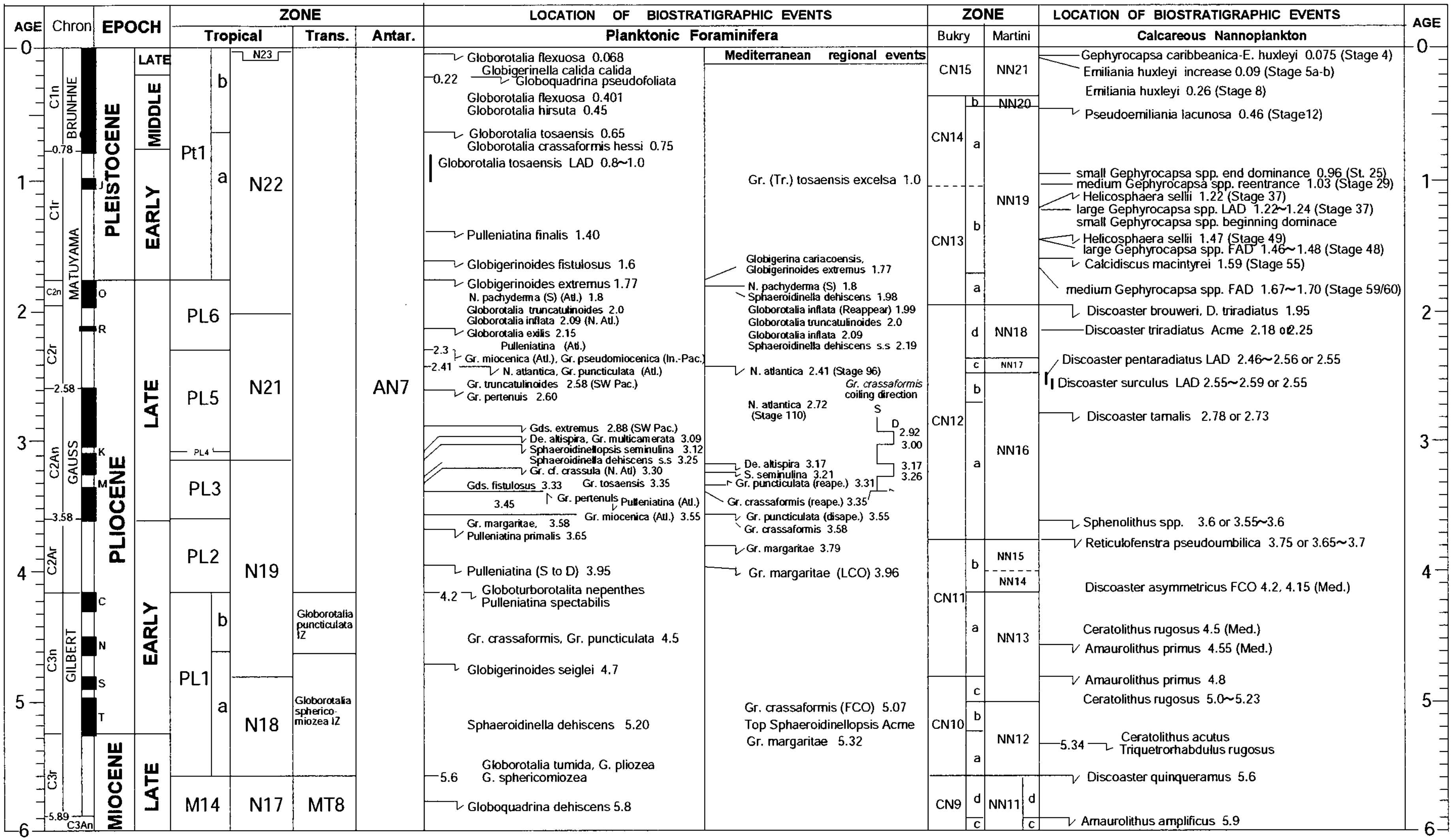
Area	Sample No.		Depth(m)	Sampling Depth(m)	Abundance of Planktonic Foraminife	Abundance of Planktonic Foraminife	Abundance of Benthic Foraminifera	Preservation of Benthic Foraminifer	Geological Age	*Ammodiscus anguillae*	*Buzasina ringens*	*Eggerella bradyi*	*Haplophragmoides columbien*	*Haplophragmoides hancocki*	*Marsipella spp.*	*Recurvoides turbinatus*	*Rhabdammina spp.*	*Saccammina spp.*	*Cibicides refulgens*	*Ehrenbergina spp.*	*Epistominella exigua*	*Epistominella umbonifera*	*Fissurina spp.*	*Globocassidulina subglobosa*	*Melonis sphaeroides*	*Oridorsalis umbonatus*	*Pullenia bulloides*	*Pyrgo spp.*
Niue	03S2027SC01	FS01	4,754	0-0.05	F	P	F	M	Pleistocene								X		X	X			X	X		X		X
		FS03		0.2-0.25	F	P	F	M	Pleistocene	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X	X	X

Tble 1-3 Results of Radiolarian Fossils

Samples				Color	Age	Index Fossil of Age Determination																	Index Fossil of Sedimentation Environment								
Station No.	Sampling Point	Sample No.	Depth(m)		Radiolarian Age	Amphirhopalum praeypsilon Sakai	Amphirhopalum ypsilonHaeckel	Anthocyrtidium angulare Nigrini	Anthocyrtidium ehrenbergi Stoehr	Anthocyrtidium michelinae Caulet	Anthocyrtidium ophirense Ehrenberg	Axoprunum anelinum (Campbell et Clark)	Axoprunum bispiculum (Popofsky)	Buccinosphaera invaginata Haeckel	Collosphaera tuberosa Haeckel	Lamprocyrtis neoheteroporos Kling	Lamprocyrtis nigrinae (Caulet)	Pterocanium praetextum praetextum (Ehrenberg)	Pterocanium prismatium Riedel	Pterocanium trilobum (Haeckel)	Stylacontarium aquilonium (Hays)	Theocorythium trachelium trachelium (Ehrenberg)	Actinomma (?) boreale (Cleve)	Cornutella profunda Ehrenberg	Cycladophora davisiana Ehrenberg	Didymocyrtis tetrathalamus tetrathalamus (Haeckel)	Lithopera bacca Ehrenberg	Spongaster tetras tetras Ehrenberg	Spongoplegma (?) arachdophorum (Haeckel)	Suttonium praedictator Schaaf	Tetrapyle octacantha Muller
03503	03S2027SC01	FS01	0.00-0.05	dark brown	0.00-0.18 Ma					*			*	cf.				*		*		*				*		*	*	*	*
		FS02	0.10-0.15	dark brown						*					*			*		*		*		*		*	*	*	*	*	
		FS03	0.20-0.25	brown						*				*			*	*		*		*				*	*				*
		FS04	0.30-0.35	dark brown						*			*	*	*			*		*		*	*	*	*	*	*	*	*	*	*
03513	03S2327SC01	FS01	0.00-0.01	brown	0.18-0.42 Ma				*				*		cf.		*	*		cf.		*			cf.	*	*				*
		FS02	0.15-0.20	brown						*	*		*		*		*	*		*		*		*	*	*		*	*	*	
		FS03	0.26-0.28	dark brown		aff.					*		*		*			*		*		*	*		*	*	*	*	*		*
		FS04	0.30-0.33	brown							*		*		cf.			*		*		*	*		*	*		*	*		*
03514	03S2326SC01	FS01	0.00-0.03	dark brown	0.18-0.42 Ma								*													*	*		*		
		FS02	0.10-0.15	dark brown					*				cf.		*		*	*		*			*	*		*		*	*		
		FS03	0.15-0.20	brown									*		cf.			*				*	*	*	*	*	*	*			*
		FS04	0.26-0.30	dark brown	0.42-0.54 Ma				*		*		cf.		*	*		*			*		*			*	*		*		*

Table 1-4 Ichtyolith Fossils

Samples					Age	Index Fossil of Age Determination				
Staion No	Sampling Point	Sample No.	Color	Depth(m)	Ichtyolish Age	Flexed triangle 102-112	Flexed triangle shallow inbase	Triangle with high inline apex	Two triangles	Triangle with triangular projection
03503	03S2027SC01	FS01	dark brown	0.00-0.05	0.0Ma-31.7Ma	2				
		FS02	dark brown	0.10-0.15	0.0Ma-32.5Ma		1	3		2
		FS03	brown	0.20-0.25	0.0Ma-31.7Ma	1		4		
		FS04	dark brown	0.30-0.35	0.0Ma-31.7Ma	2	1	3		
03513	03S2327SC01	FS01	brown	0.00-0.01	uncertain					
		FS02	brown	0.15-0.20	0.0Ma-19.2Ma			1	2	
		FS03	dark brown	0.26-0.28	uncertain					
		FS04	brown	0.30-0.33	uncertain					
03514	03S2326SC01	FS01	dark brown	0.00-0.03	0.0Ma-63.9Ma					1
		FS02	dark brown	0.10-0.15	uncertain					
		FS03	brown	0.15-0.20	0.0Ma-32.5Ma			1		1
		FS04	dark brown	0.26-0.30	0.0Ma-32.5Ma			1		



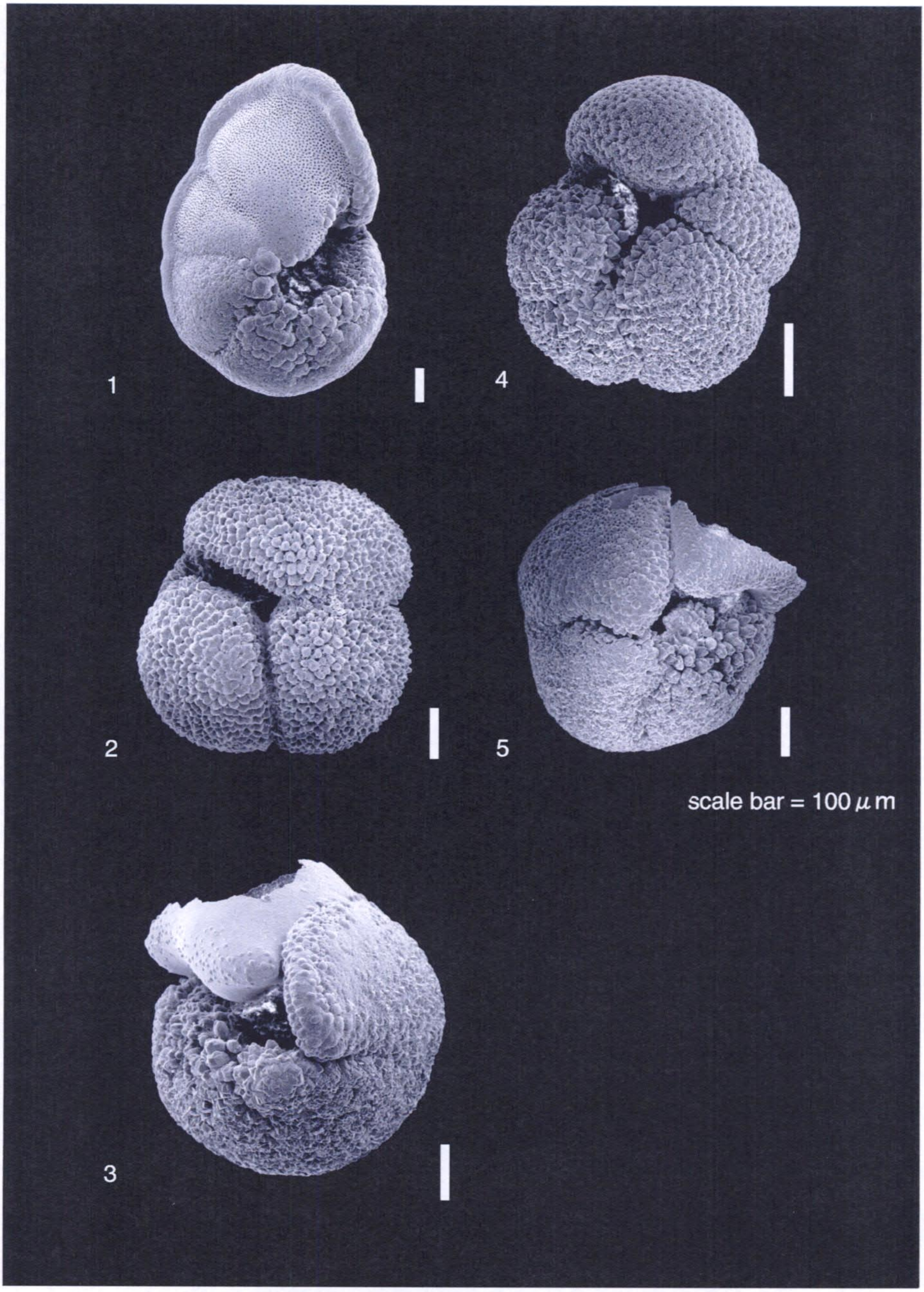
FOC, first common occurrence; Gr., Globorotalia; Gds., Globigerinoides; De., Dentoglobigerina; N., Neogloboquadrina; S., Sphaeroidinellopsis.
J, Jaramillo; O, Olduvai; R, Reunion; K, Kaena; M, Mammoth; C, Cochiti; N, Nunivak; S, Sidufjall; T, Thvera

(Berggren et al., 1995)

Fig. 1 Biostratigraphic Basis of Calcareous Microfossil and Geologic Time in Low Latitudes

Electron Microscope Photograph of Planktonic Forafeminifera

1. *Globorotalia tumida* (Brady). Umbilical view, Sample from 03S2027SC01-FS03.
2. *Globigerinoides conglobatus* (Brady). Umbilical view, Sample from 03S2027SC01-FS03.
3. *Globorotalia truncatulinoides* (d' Orbigny). Umbilical view, Sample from 03S2027SC01-FS03.
4. *Neogloboquadrina dutertrei* (d' Orbigny). Umbilical view, Sample from 03S2027SC01-FS03.
5. *Globorotalia ronda Blow.* Umbilical view, Sample from 03S2027SC01-FS03.


1
4
2
5
3
scale bar = 100 μm

Microscopic Phographs of Radiolarian Fossils

fig. 1a–1b. *Axoprunum bispiculum* (Popofsky)

03S2027SC01 FS01 Photo ID DSCN5314, 5315.

fig. 2a–2b. *Stylocontarium acquilonium* (Hays)

03S2326SC01 FS04 Photo ID DSCN4259, 4260.

fig. 3. *Buccinosphaera invaginata* Haeckel

03S2027SC04 FS01 Photo ID DSCN3986.

fig. 4. *Collosphaera tuberosa* Haeckel

03S2027SC01 FS04 Photo ID DSCN3983.

fig. 5. *Actinomma* (?) *boreale* (Cleve)

03S2027SC01 FS04 Photo ID DSCN4077

fig. 6. *Cornutella profunda* Ehrenberg

03S2027SC01 FS02 Photo ID DSCN5064

fig. 7. *Didymocyrtis tetrathalamus tetrathalamus* (Haeckel)

03S2326SC01 FS04 Photo ID DSCN4373

fig. 8. *Spongoplegma* (?) *arachdophorum* (Haeckel)

03S2027SC01 FS02 Photo ID DSCN5121

fig. 9. *Cycladophora davisiana* Ehrenberg

03S2327SC01 FS04 Photo ID DSCN5214

fig.10. *Lithopera bacca* Ehrenberg

03S2027SC01 FS04 Photo ID DSCN3943.

fig.11. *Tetrayple octacantha* Muller

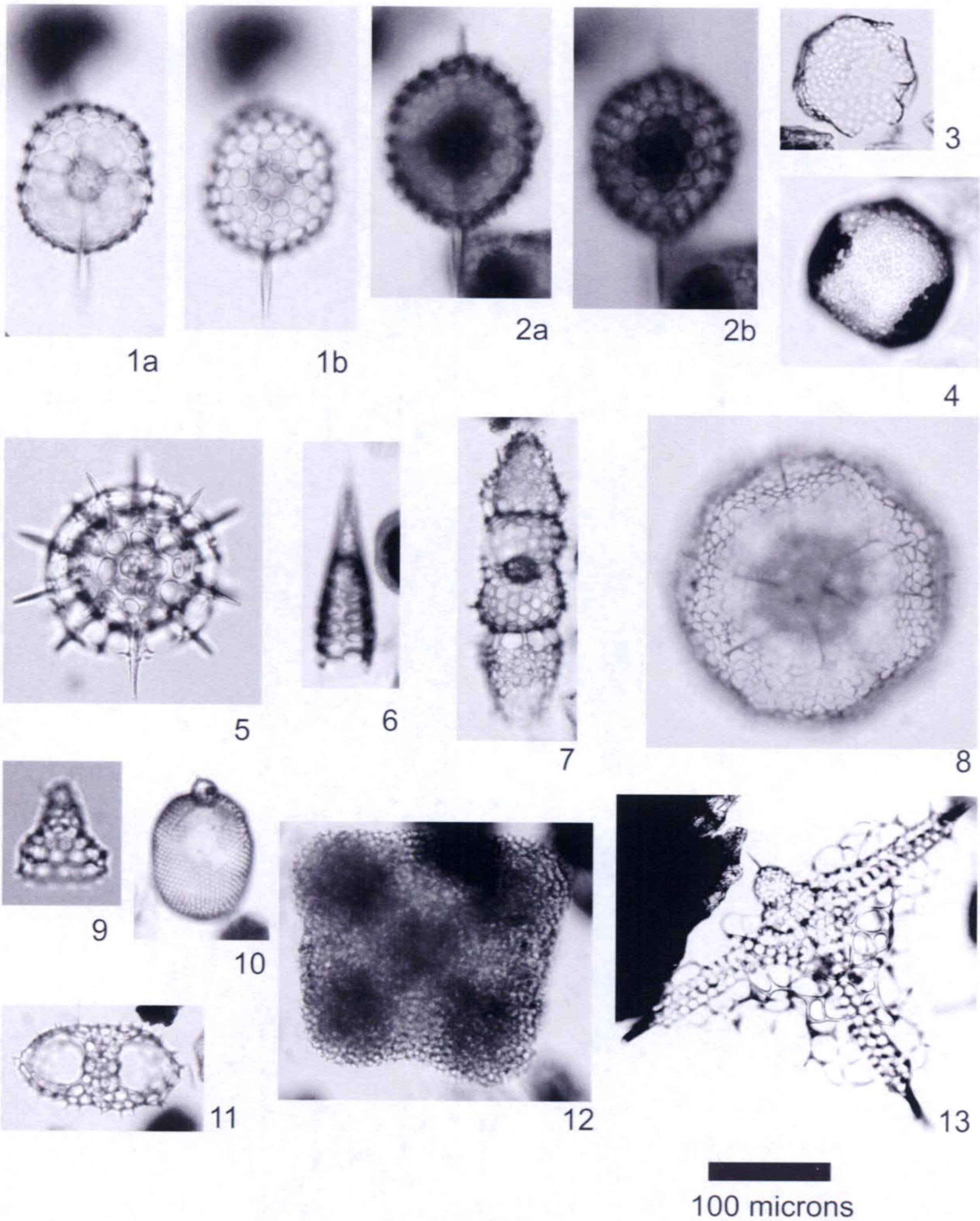
03S2327SC01 FS04 Photo ID DSCN5219

fig.12. *Spongaster tetras tetras* (Haeckel)

03S2327SC01 FS02 Photo ID DSCN4734

fig.13. *Suttonium praedictator* Schaaf

03S2027SC01 FS02 Photo ID DSCN5130



Radiolarian Fossils

Microscopic Phographs of Ichtyolish Fossils

fig.1. *Triangle with triangular projection* Helms and Riedel

03S2027SC01 FS02

fig.2. *Flexed triangle shallow inbase* Doyle *et al.*

03S2027SC01 FS04

fig.3. *Triangle with high inline apex* Doyle et al.

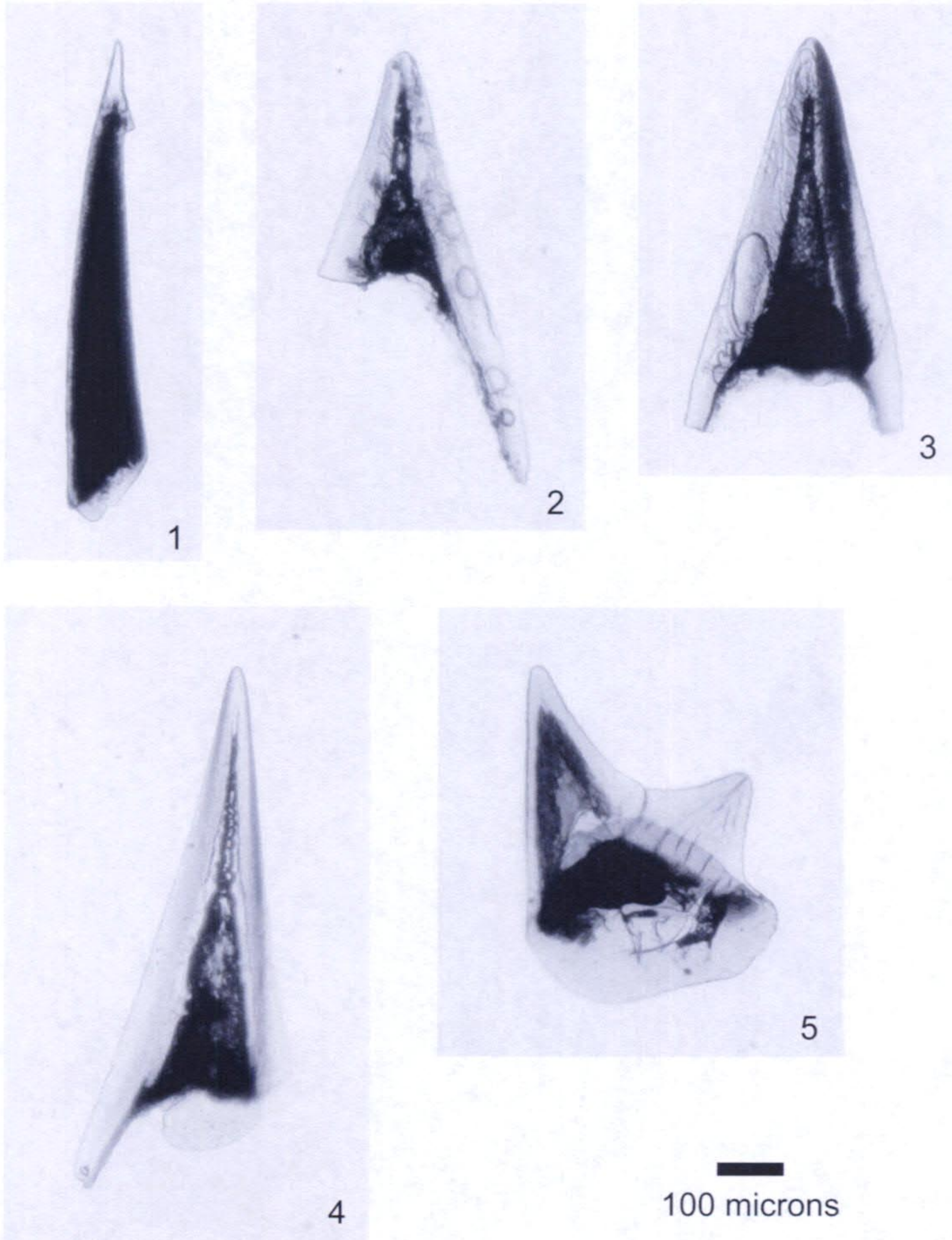
03S2027SC01 FS02

fig.4. *Triangle with triangular projection* Helms and Riedel

03S2027SC01 FS01

fig.5. *Two triangles* Doyle et al.

03S2327SC01 FS02



Ichtyolith Fossils

[Appendix Document 2]
Result of Microscopic Observation of Rock Thin Section

The rock sample used for thin section observation is listed in Table 2-1.

Table 2-1 Sample Information

Sea Area	Station No.	Sample No.	Water Depth (m)	Geologic Occurrence	Remarks
Niue	03511	03S2227AD01 TS01	1,791	Pebbly crust	Aphyric volcanic rock
		03S2227AD01 TS01	1,791	Pebbly crust	Aphyric volcanic rock (calcareous concretion)

1. **Microscope Observation of Rock Thin Section**

The result of microscopic observation of rock thin section is given in Table 2-2. Detailed description sheet and microscope photographs of thin section are attached in the last part of the report.

Table 2-2 Results of Thin Section Observation

Sample No.		Rock	Phenochryst				Groundmass			Alteration		Remarks
			pl	cpx	ho	amy	pl	op	gl	sm		
03S2227 AD01	TS01	Porous aphyric volcanic rock	2	1	<1	15	50	10	20	10		Amygdaloidal, hyalopilitic with flow texture Hypocrystalline cryptocrystalline,
	TS02	Porous aphyric volcanic rock (with calcareous concretion)	2			10	50	5	20	10		Amygdaloidal Hyalopilitic with flow texture Hypocrystalline

pl: plagioclase, cpx: clinopyroxene, ho: hornblende, amy: amygdule, op: opaque minerals
gl: glass, sm: smectite
Digit explains maximum content of each mineral in % (sum sometimes over 100%).

Description of rock

(1) 03S2227 AD01 TS01 Porous cryptocrystalline basalt

The sample is amygdaloidal, hyalopilitic with flow texture, hypocrystalline, cryptocrystalline rock.

Phenochryst consists of plagioclase, clinopyroxene, and hornblende. They are very small in amount. Amygdules are irregulary distributed in the rock.

Groundmass is mainly composed of plagioclase. Other minerals are opaque minerals and glassy materials. Columnar to acicular plagioclase showing significant flow texture.

Extent of alteration is, hyalopilitic, and alteration minerals (smectite?) partly occur as the fillings of amygdules.

(2) 03S2227 AD01 TS02 Aphyric porous basalt catching manganese crust? with calcareous concretion

The sample is amygdaroidal and hyalopilitic with flow texture and hypocrystalline rock.

It includes small content of plagioclase as phenochryst. Amygdule is irregularly scattered in the rock.

Groundmass is mainly consists of plagioclase and other materials are opaque minerals and glassy materials. It shows dominant flow texture due to columnar to needle-like (acicular).

On alteration, glassy groundmass is devitrified and bearing clay minerals (smectite?).

The sample contains calcareous pebble (as xenolith?) and there is observed foraminifer fossils such as *Globigerinae(?)* in cryptocrystalline groundmass. In the pebble, there are included many altered basalt (smectite-bearing, devitrified), tuff, coarse plagioclase crystalline fragment

Manganese oxides are seen as if it were coated, or grown up inside of a rather big cavity whose cavity was filled up by calcareous pebbles in later stage. Manganese oxides grow up inside the cavity taking stromatolite-like shape and they penetrate into basalt (epigenetic).

2. Summary

The samples observed under microscope are both porous, cryptocrystalline basalt. They are amygdaloidal basalt with hyalopilitic appearance, and show hypocrystalline texture. Small content of plagioclase is associated as phenochryst.. The groundmass shows significant flow texture due to columnar to needle-like (acicular) plagioclase. Other than that, opaque minerals and glassy materials are contained.

Concerning alteration, clay minerals (smctite?) bear in the glassy groundmass. The no.2 sample (03S2227 AD01 TS02) catches mangansese crust(?) with calcareous pebble as nucleus.

Sample ID : 03S2227 AD01 TS01

Rocks : porous aphyric basalt

Observation(eye) :

Microscopic Observation

Texture :
amygdaloidal、 hyalopilitic with flow texture、 hypocrystalline, cryptocrystalline

Phenocryst :
Very little amount of plagioclase, clinopyroxene

Minerals	Shape	Grain size	Content	Description
Plagioclase	subhedral	0.5～1mm	2%	zonal texture
clinopyroxene	sub to euhedral	300～500 μ	1%	partly sector texture
hornblende	subhedral, fused	200～400 μ	<1%	opathitic rims
amygdule	round	0.1～5mm (Av.0.5～1mm)	10～15%	irregularly distributed

Groundmass :
Columnar to acicular plagioclase aligns with significant flow texture.

Minerals	Shape	Grain size	Content	Description
Plagioclase	Columnar ～ acicular	50～300 μ	40～50%	Significant flow texture intersertal
Opaque mineral	eu ～ subhedral, granular	10～ 50 μ	5～10%	filling up
Glassy groundmass	xenomorphic	10～ 50 μ	～20%	devitrified

Alteration :
Clay minerals (smectite?) occur partly of hyalopilitic groundmass and fillings of amygdule (glassy alteration minerals?)

Description of Altered Mineral :

Mineral	Shape	Grain Size	Content	Description
Smectite	Irregular	10～ 50 μ	5～10%	Altered mineral of glassy groundmass, fill up amygdule

Remarks :

Sample ID : 03S2227 AD01 TS02

Rock : aphyric porous basalt catching manganese crust? with calcareous concretion

Observation(eye) :

Microscopic Observation

Texture :

Amygdaloidal, hyalopilitic with flow texture, hypocrystalline

Phenocryst :

Minerals	Shape	Grain Size	Content	Description
plagioclase	Subhedral	~500 μ	2%	zonal texture
amygdule	round ~ elliptical	0.1~2mm (Av.0.5~0.8mm)	~10%	irregularly distributed

Groundmass :

columnar~needle-like plagioclase makes flow texture

Minerals	Shape	Grain Size	Content	Description
Plagioclase	Columnar ~ acicular	20~ 50 μ	40~50%	Significant flow texture
		5~ 50 μ	~5%	intersertal
opaque minerals	euhedral~ xenomorphic, granular	10~ 50 μ	~20%	filling up
Glassy groundmass	xenomorphic			devitorified

Alteration

Hyalopilitic groundmass is altered into smectite(?), devitrified

Description of Altered Mineral :

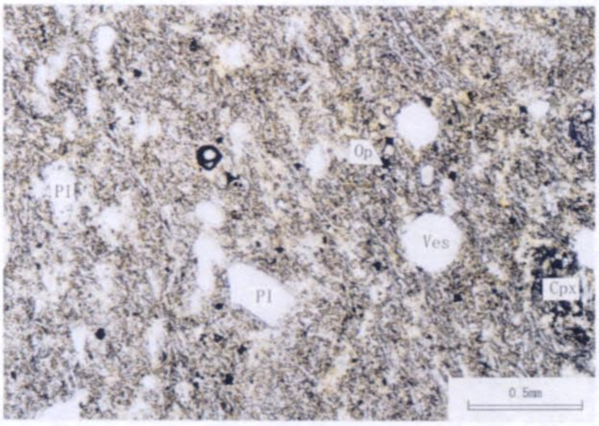
Mineral	Shape	Grain Size	Content	Description
smectite	Irregular	5~ 40 μ	~10%	Ggroundmass is altered and partly devitrified. Smectite occurs coating the inside wall of amygdule.

Remarks :

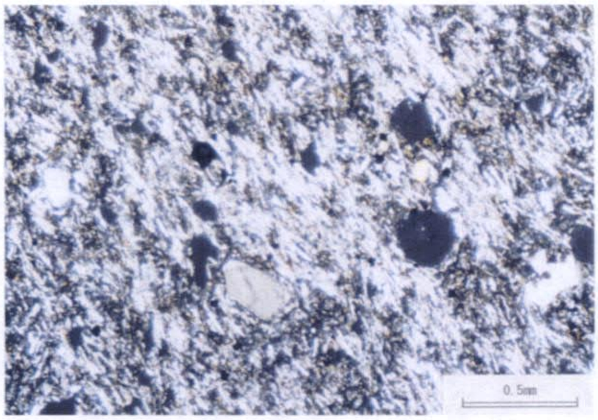
Calcareous pebble (xenolith?): Foraminifer fossils such as *Globigerinae(?)* in cryptocrystalline groundmass. Grain size ranges 50~800 μ . Pebbles include many fragments of altered basalt (smectite-bearing, devitrified), tuff, and fragments of coarse plagioclase crystals.

Manganese oxides: Manganese oxides are seen as if it were coated, or grown up inside of a rather big cavity. The cavity seems filled up by calcareous pebbles in later stage. Manganese oxides grow up inside the cavity taking stromatolite-like shape and they penetrate into basalt (epigenetic).

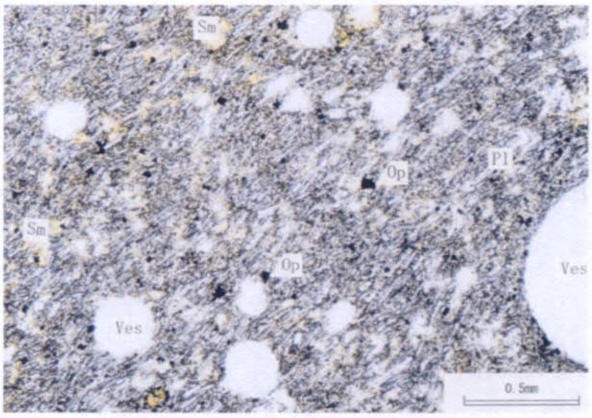
03S2227AD01 TS01① (plane - polarized)



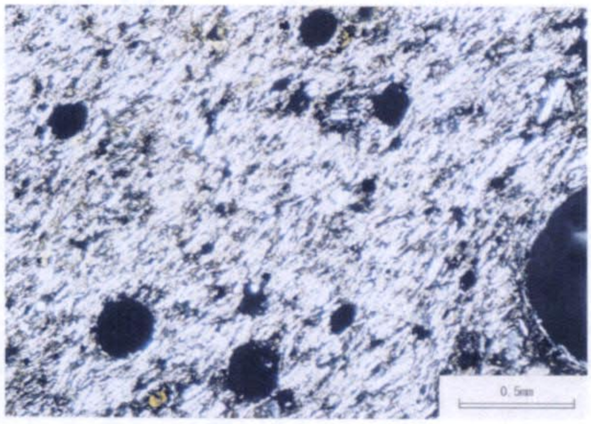
(crossed - polarized)



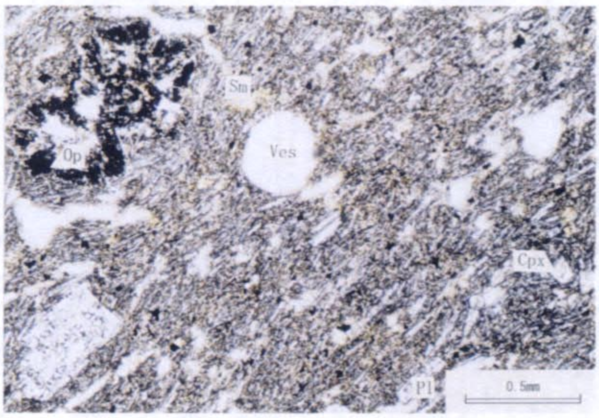
03S2227AD01 TS01② (plane - polarized)



(crossed - polarized)



03S2227AD01 TS01③ (plane - polarized)



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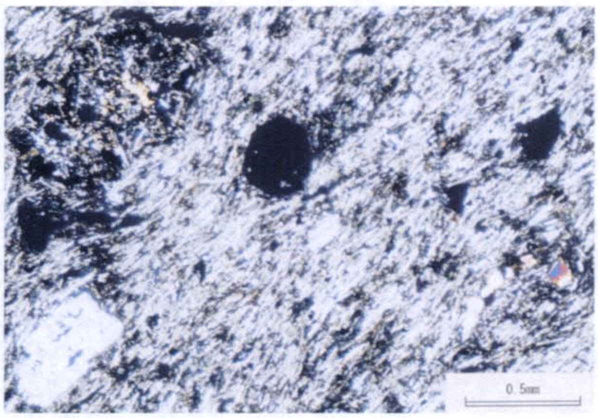
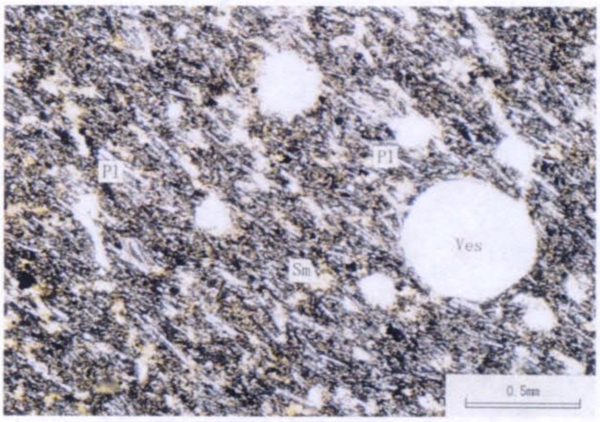
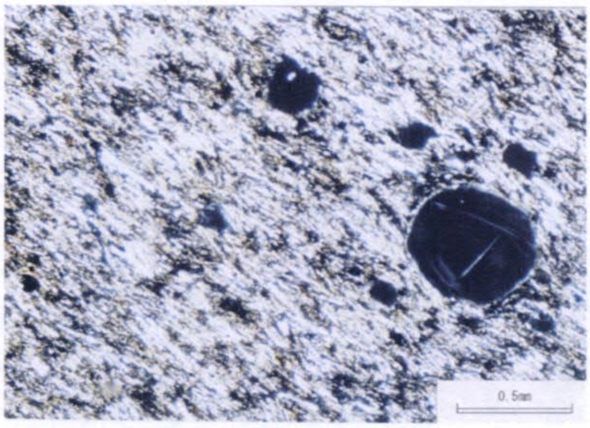


Photomicrographs (1)

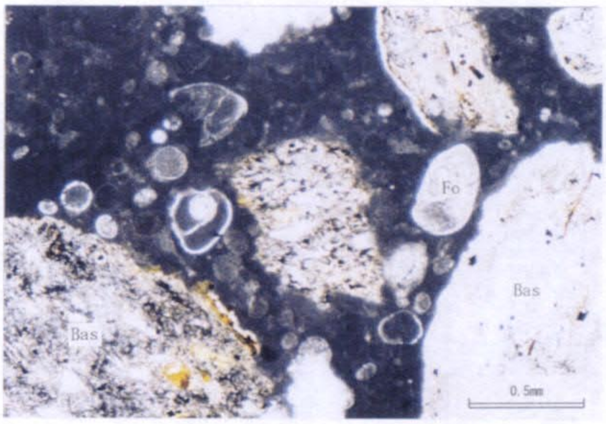
03S2227AD01 TS02① (plane - polarized)



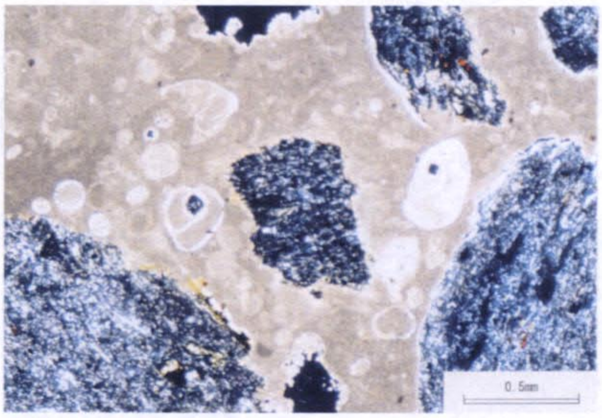
(crossed - polarized)



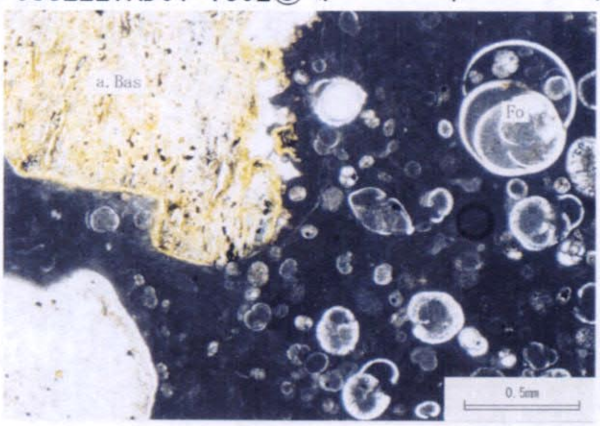
03S2227AD01 TS02② (plane - polarized)



(crossed - polarized)



03S2227AD01 TS02③ (plane - polarized)



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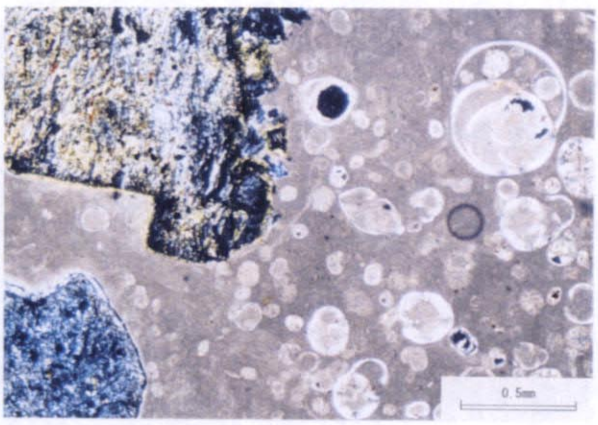
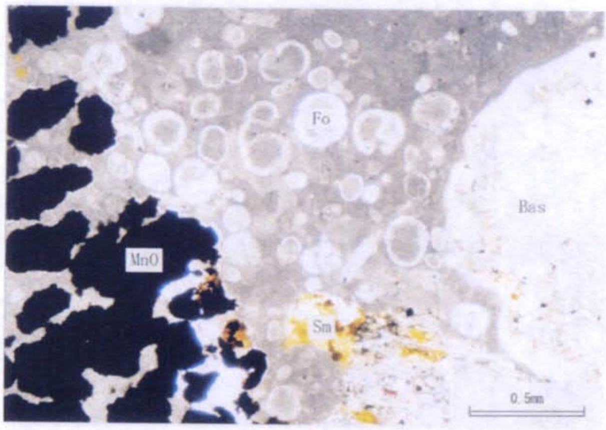
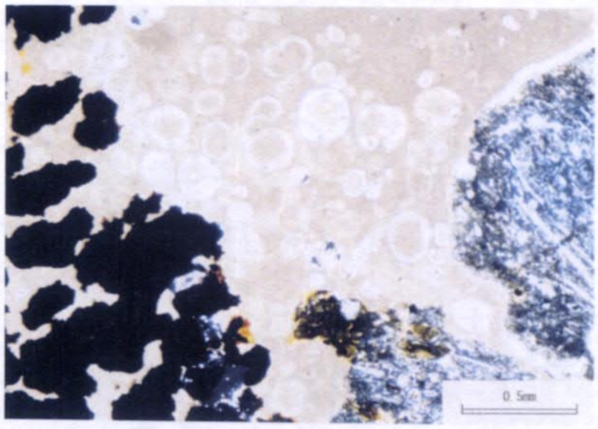


Photomicrographs (2)

03S2227AD01 TS02④ (plane - polarized) (crossed - polarized)





Photomicrographs (3)

[Appendix Document 3] Analysis Method of Manganese Oxides

Chemical analyses of 22 samples of manganese oxides (manganese nodules, crust) were conducted at the Odate Technical Center Corp.

Eight elements were analyzed for manganese nodule samples coalescent nuclei such as, Co, Ni, Cu, Mn, Fe, LOI, H_2O^+, H_2O^-, and thirty six elements were analyzed for manganese nodules without nuclei and crust samples such as, Co, Ni, Cu, Mn, Fe, Pb, Zn, Ti, Mo, V, Si, Al, Ca, Na, K, P, Ba, Sr, Pt, LOI, H_2O^+, H_2O, REE (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu). Analytical method and the detection limit are shown in Table 3-1.

Table 3-1 Analysis Method and Detection Limit

Element	Co	Ni	Cu	Mn	Fe	Pb
Method	ICP-emiss.	ICP-emiss .	ICP-emiss.	ICP-emiss.	ICP-emiss.	ICP-MS
Detection Limit	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%
Element	Zn	Ti	Mo	V	Si	Al
Method	ICP-MS	ICP- emiss.	ICP-MS	ICP-MS	ICP-emiss.	ICP-emiss.
Detection Limit	0.01%	0.01%	0.01%	1ppm	0.01%	0.01%
Element	Ca	Na	K	P	Ba	Sr
Method	ICP- emiss.	ICP- emiss.	ICP-emiss.	ICP-emiss.	ICP-MS	ICP-MS
Detection Limit	0.01%	0.01%	0.01%	0.01%	10ppm	1ppm
Element	Pt	Ig-loss	H_2O^+	H_2O^-	La	Ce
Method	Fire-Assey-ICP				ICP-MS	ICP-MS
Detection Limit	0.1ppm	0.01%	0.01%	0.01%	0.5ppm	0.5ppm
Element	Pr	Nd	Sm	Eu	Gd	Tb
Method	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS
Detection Limit	0.1ppm	0.5ppm	0.1ppm	0.1ppm	0.1ppm	0.1ppm
Element	Dy	Ho	Er	Tm	Yb	Lu
Method	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS
Detection Limit	0.1ppm	0.1ppm	0.1ppm	0.1ppm	0.1ppm	0.1ppm

For rare earth elements, obtained values are normalized on the basis of the value of chondrite and North American Shale Standard as below.

Table 3-2 REE Value used for Normalization

	La (ppm)	Ce (ppm)	Pr (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)	Gd (ppm)
Chondrite	0.340	0.910	0.121	0.640	0.195	0.073	0.260
North American Shale Standards	32.00	70.00	7.900	33.00	5.700	1.240	5.200

	Tb (ppm)	Dy (ppm)	Ho (ppm)	Er (ppm)	Tm (ppm)	Yb (ppm)	Lu (ppm)
Chondrite	0.047	0.300	0.080	0.200	0.032	0.220	0.034
North American Standards	0.850		1.040	3.400	0.500	3.100	0.480

Chondrite value: after Wakita et al. (1971)

North American Shale Standards : after Haskin et al. (1968)